CORROSION CONSIDERATIONS IN OUTSIDE PLANT

Purpose: The purpose of this addendum is to provide criteria to determine whether copper or aluminum type shields should be used with direct burial cable.

Additions:

Paragraphs 1.05 and 1.06 GENERAL
Paragraph 5. ALUMINUM SHIELD MATERIALS
Paragraph 6. CRITERIA FOR SELECTION OF ALUMINUM CABLE SHIELDS FOR DIRECT BURIAL CABLES
Paragraph 7. MEASUREMENT OF EARTH RESISTIVITY
TABLE III - RANGE OF RESISTIVITY VALUES FOR SEVERAL TYPES OF SOILS
FIGURE 7 - ESTIMATED EARTH RESISTIVITY IN THE UNITED STATES
FIGURE 8 - EARTH RESISTIVITY MEASUREMENT PROCEDURE

1.05 REA has recommended 5-mil (.005 inch) copper shields for buried cable in non-gopher infested areas and either 10-mil (.010 inch) copper or 6-mil (.006 inch) bimetallic shields containing copper and stainless steel for areas requiring gopher protection. Even though experience has proven that copper type shields perform satisfactorily, the relatively high cost of copper and its fluctuating availability has prompted research and development efforts towards the use of alternate metals or combinations of metals for shields in buried cables.

1.06 A desirable shielding material, in addition to being readily available and economical should exhibit the following characteristics:

a. Corrosion resistance
b. Resistance to gopher penetration
c. Flexibility
d. Ease in forming and corrugating
e. High conductivity

A logical shield choice to satisfy most of the above items is aluminum. However, the corrosion resistance and gopher protection afforded by aluminum are questionable. In an effort to rectify these two shortcomings, extensive tests have been conducted and it has been found that under certain conditions, shields containing aluminum may be used.

5. ALUMINUM SHIELD MATERIALS

5.1 Where gopher protection is needed, the shield may consist of 3-mils (.003 inch) of AISI Type 304 stainless steel laminated to a 6-mil (.006 inch) plastic-coated aluminum shield. The stainless steel provides the gopher protection and the aluminum the conductivity.

5.2 For non-gopher infested areas, an 8-mil (.008 inch) plastic-coated aluminum shield may be used. Tests have shown that the plastic coating provides a good degree of corrosion protection in moderately corrosive soils.

6. CRITERIA FOR SELECTION OF ALUMINUM CABLE SHIELDS FOR DIRECT BURIAL CABLES

There may be corrosion problems in some soils despite the plastic coating on the aluminum shield, especially where a galvanic couple may exist between the aluminum and a more noble metal such as copper. A metal cathodic to aluminum will not always be in the vicinity of an exposed shield; however, the possibility does exist. The thought is often expressed that since buried cables have a polyethylene jacket covering the shield, the shield will not usually be exposed to the soil. However, cable sheath damage during installation caused by construction personnel, equipment, rocks, sand abrasion, and handling does occur. Lightning and rodent damage continues to occur and the possibility of manufacturing flaws also exists. In some areas holes in the cable's outer jacket may exist in many buried cable sections (between splice enclosures) with a greater incidence expected in gopher areas. Improved cable designs and construction practices could substantially reduce this damage, but are not likely to eliminate it completely.

6.1 The evaluation of the corrosivity of a soil is complex. Some of the soil properties that affect corrosion are earth resistivity, pH, drainage or aeration, moisture content, and soluble salts present. These properties can vary considerably in an exchange area.

6.2 Since it is not practicable to make detailed soil tests at the proposed cable burial depth at frequent intervals along the cable route, some simple method may be used to determine soil corrosivity. Experience has shown that of all the factors involved in the corrosion of aluminum, a low earth resistivity is usually present where severe corrosion occurs. An exception to this for coated aluminum would be in sand saturated with salt water (resistivity of approximately 100 ohm-centimeters) where the coated aluminum is expected to perform reasonably well.

6.3 Extensive studies have shown that a plastic coated aluminum shield should be satisfactory for buried cable if the earth resistivity at the cable burial depth is <u>2500 ohm-centimeters or greater.</u> This is based on observations of many corrosion specimens.

6.4 Earth resistivity is affected by the type of soil, soluble salts, moisture content and even soil temperature. It may vary widely within a short distance. The lowest resistivity exists during a wet season at warm temperatures. If it is desired to determine the earth resistivity at a given time of year, at a given location, the only practical way is to measure it.

6.5 Safety factors are included in the cable design to compensate for some error in the measurements. The shield is coated on both sides with a plastic film to prevent moisture from contacting the aluminum surface except at a point of damage. The plastic film also provides a mechanism to bond the aluminum shield to the cable's outer jacket which makes the cable more flexible. In addition, the possibility of lightning damage in low resistivity soil is less than that expected in high resistivity soil since the arcing distance of a lightning stroke between the soil and the shield is proportional to the square root of the earth resistivity. Therefore, as earth resistivity is decreased, the number of lightning strokes between earth and shield should be decreased.

6.6 Earth resistivity may vary widely over short distances but a few measurements will indicate the kinds of locations that would have the lowest resistivities. It is recommended that earth resistivity measurements be made at every load point location. However, after experience has been gained, relatively few measurements may be needed along a proposed cable route to determine whether earth resistivities are in a range that would permit the use of aluminum cable shield. The following are illustrations of locations where low resistivities are to be expected:

a. Swamp or marshy locations.
b. Poorly-drained pockets where soil salts would accumulate.
c. Very dry areas, old lake beds or alkali spots.
d. Cinder or dumps.
e. In urban areas where streets are salted.
f. Manholes or other locations where drainage water collects.
g. Areas where soils may be saturated with drainage from irrigated fields.

Some measurements may indicate drastic drops in resistivity along the route. These drops are commonly referred to as "hot spots" in the pipeline industry. If these "hot spots" do not drop below 2500 ohm-centimeters, they may be ignored. However, if they drop below 2500 ohm-centimeters, the criteria for using aluminum shields in buried cable have not been met. As a rule of thumb, if the average of all measurements taken is greater than 3500 ohm-centimeters and no more than 10 percent of

all the measurements taken are less than 2500 ohm-centimeters, aluminum may be used. Otherwise, copper should be used. The same type of shield should be used throughout the exchange area for a given contract.

6.7 An empirical guide for determining where aluminum shielded cable may be used is shown in Figure 7. <u>It is only a guide and should be treated as such since isolated areas may have low or high earth resistivity without the map reflecting it.</u> In all areas of the country one should be certain of the earth resistivity before deciding on the use of aluminum shielding. Earth resistivity data for the exchange area obtained from other utilities may be used in lieu of making additional measurements.

7. MEASUREMENT OF EARTH RESISTIVITY

7.1 There are a number of ways to measure earth resistivity. Some involve excavation to the burial depth and some do not. The most accurate method is to obtain some soil at the cable burial depth and measure the resistivity in the laboratory under controlled conditions which include saturating the soil with distilled water. A field measurement can be made at the soil burial depth using "Shepard Canes." However, the easiest and most practical way is to use the four terminal method shown in Figure 8. Four small test electrodes (stubs of No. 8 AWG wire will serve) are placed to the same depth and equal distances apart in a straight line. Four separate lead wires connect the electrodes to the four terminals on the instrument, as shown. Hence, the name of this test: the four terminal method. A set of test leads cut to length helps to expedite measurements.

7.2 Dr. Frank Wenner of the U. S. National Bureau of Standards developed the theory behind this in 1915. He showed that if the electrode depth "A" is kept small compared to the distance between electrodes "B", the following equation applies:

$$\rho = 2\pi BR$$

Where ρ is the average earth resistivity to depth "B" in ohm-centimeters, π is the constant 3.1416, "B" is the distance between the electrodes in centimeters, and "R" is the instrument reading in ohms.

7.3 Since the cable is usually buried at a depth of 2 to 3 feet, the average earth resistivity should be measured to at least a four foot depth. The electrode depth should not exceed 10 percent of the electrode spacing dimension. A three inch electrode depth should be adequate. Black vinyl tape may be placed 3 inches from the ends of the electrodes as a depth gage. Assuming an instrument reading of 30 ohms is obtained at four foot electrode spacing, the earth resistivity would be calculated as follows:

$$\begin{aligned}\rho &= 2\pi BR \\ &= 2(3.14)\ (4\text{ ft.} \times 12\text{ in./ft.} \times 2.54\text{ cm/in.})\ (30) \\ &= 766\ (30) \\ &= 22{,}980\text{ ohm-centimeters}\end{aligned}$$

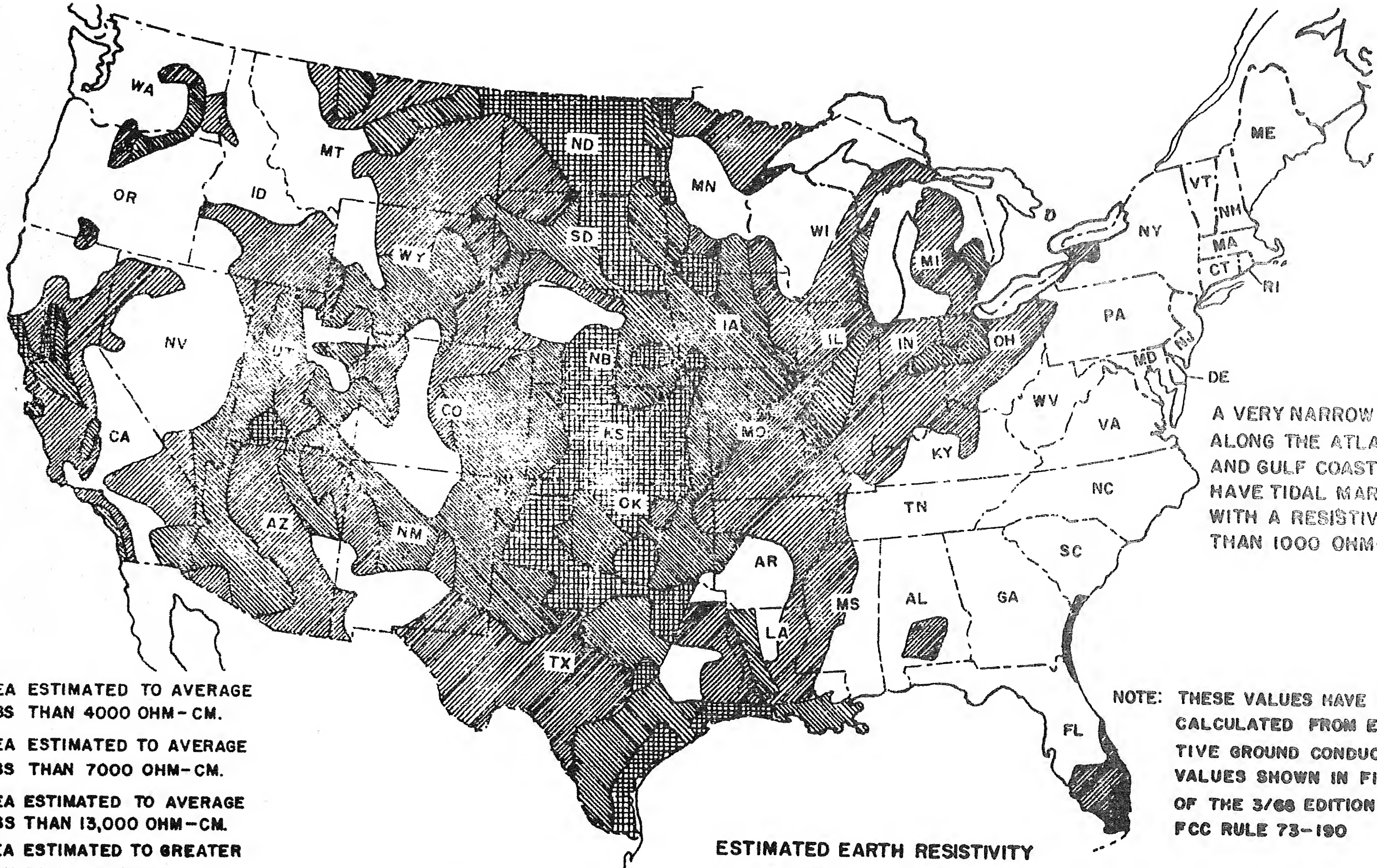
Therefore, if the four foot electrode spacing is maintained, the earth resistivity is 766 times the instrument reading in ohms. Since 766 may be an inconvenient number to multiply by, an electrode spacing of 5.2 feet may be used. The instrument reading in ohms would then be multiplied by 1000.

7.4 Typical earth resistivity values to be expected are given in Table III.

TABLE III

RANGE OF RESISTIVITY VALUES FOR SEVERAL TYPES OF SOILS

Soil Type	Resistivity ohm-Centimeters
Sand saturated with sea water	100 - 200
Marsh	200 - 400
Clay	200 - 15,000
Sand and gravel	5,000 - 100,000
Clay mixed with sand and gravel	1,000 - 135,000
Shale	1,000 - 50,000
Rock	50,000 - 1,000,000
Limestone	500 - 400,000



A VERY NARROW AREA ALONG THE ATLANTIC AND GULF COASTS COULD HAVE TIDAL MARSH SOIL WITH A RESISTIVITY LESS THAN 1000 OHM-CM.

AREA ESTIMATED TO AVERAGE LESS THAN 4000 OHM-CM.

AREA ESTIMATED TO AVERAGE LESS THAN 7000 OHM-CM.

AREA ESTIMATED TO AVERAGE LESS THAN 13,000 OHM-CM.

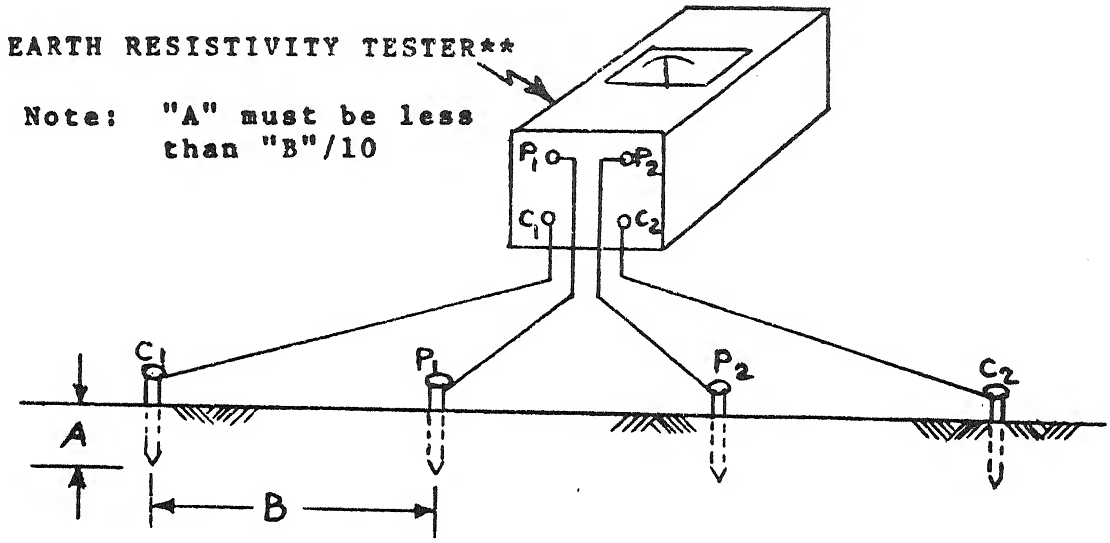
WHITE AREA ESTIMATED TO GREATER THAN 20,000 OHM-CM.

RESISTIVITY OF SEAWATER IS NOT SHOWN ON MAP BUT IS ASSUMED TO BE 100 OHM-CM.

NOTE: THESE VALUES HAVE BEEN CALCULATED FROM EFFECTIVE GROUND CONDUCTIVITY VALUES SHOWN IN FIG. R3 OF THE 3/68 EDITION OF FCC RULE 73-190

ESTIMATED EARTH RESISTIVITY IN THE UNITED STATES

Figure 7



Electrodes are placed in a straight line at equal intervals.

**ASSOCIATED RESEARCH, INC. MODEL 293, MODEL 263A, BIDDLE CO. 563, or an equivalent

Figure 8. EARTH RESISTIVITY MEASUREMENT PROCEDURE

CORROSION CONSIDERATIONS IN OUTSIDE PLANT

CONTENTS

1. GENERAL

1.01 This section is intended to provide REA borrowers, consulting engineers and other interested parties with technical information for use in the design and construction of REA borrowers' telephone systems. It discusses in particular various aspects of corrosion which should be considered during the early stages in the preparation of a system design.

1.02 REA TE & CM-218, "Plant Annual Cost Data for System Design Purposes," gives cost data showing the depreciation rates and maintenance expenses to be applied to the various plant items in different areas throughout the United States. However, within these general areas there may exist particularly corrosive elements which would greatly increase the maintenance expense and cause the early replacement of some plant items. This results in a severe economic burden to the operating telephone company.

1.03 Corrosive atmospheric conditions may exist over an entire service area of a telephone system, but are more generally confined to relatively small areas within the total service area. Rural atmospheres, which are relatively free from contaminants, represents approximately 80% of the total land area of the United States. Therefore, exposed metals are expected to experience their longest possible service life when placed in rural areas. Galvanized steel has long been used in the telephone and electric power utilities and it is not uncommon to learn of conductors and strand still in use after 40 years of service. The life expectancy of galvanized steel will vary in accordance with the amounts of contaminants present in the atmosphere to which it is exposed. In very severe corrosive atmospheres the Class A galvanized coatings on steel conductors and strand may be protective for as little as 3 or 4 years.

1.04 The processes of corrosion are not always simple and their effects are not easily predicted. In many cases the effects of one type of corrosion will cloud the effects of another type so that it is difficult to recognize either. In the paragraphs that follow a general introduction to the study of corrosion is given and an attempt made to provide guidelines for the design of systems affected by different types of severe corrosive atmospheric or soil conditions. The descriptions given in paragraph 3 on the corrosion behavior of the different materials used in telephone outside plant construction are to be expected only in areas of severe exposure.

2. THEORY AND MECHANISM OF CORROSION

2.01 Electrochemical Theory

2.011 Corrosion may follow any one of several general patterns. Basically stated, corrosion results from the instability of a construction material to the environment in which it is placed. For a metal to corrode, both moisture and air (oxygen) must be present. All materials, both organic and inorganic, can react and may eventually lose their usefulness for a given application because of inadvertent mechanical, chemical or electrochemical actions thereon. As a result, their usefulness for a given application is impaired. Some nonmetals tend to decompose, usually as the result of chemical interaction with some component of their environment. Metals tend to revert to their stable states through the process of oxidation.

2.012 Corrosion is the result of electrochemical or chemical reaction between a metal and its surroundings. Most of the destructive effects of corrosion are due to electrochemical reaction. The basic requirements for electrochemical corrosion are that (1) anodes and cathodes must be present to form a cell, (2) direct current must flow, and (3) there must be an electrically conducting medium. The anodes and cathodes could be close together (local cells) or far apart. The current can be self-induced or it can be impressed on the system from an outside source. The conducting medium can be water, contaminated water or any solution which can conduct electricity (electrolyte).

The metal at the anode dissolves and becomes ionized by losing electrons which are left behind in the metal. These electrons travel through the metal to the cathode where they are accepted by hydrogen ions, creating hyrdrogen gas. The generally accepted concept for flow of current is opposite to the direction of electron flow. The conductive solution or electrolyte allows the completion of the circuit. The current leaves the metal at the anode, flows through the solution to the cathode and then passes through the metal from the cathode to the anode, thus completing the circuit. The quantity of direct current which passes through the cell is directly proportional to the amount of metal that corrodes. For example, 1 ampere for one year will corrode about 20 pounds of steel.

2.013 If the hydrogen gas stays on the cathode and forms an insulating blanket, polarization results. Polarization intereferes with current flow, so corrosion is decreased or stopped. Oxygen, which is usually present, combines with the hydrogen insulating blanket to form water, thus removing the hydrogen film. Current flows and corrosion proceeds. This is depolarization, or in this case, cathodic depolarization because it occurs at the cathode. Polarization may also occur at the anode because of heavy concentrations of metal ions. In the presence of moisture the metal ions react with OH ions from the solution to form hydroxides which in turn react with oxygen to form oxides.

2.02 Types of Corrosion

2.021 Galvanic Corrosion

2.0211 This type of corrosion occurs when two dissimilar metals are coupled together electrically in a conductive solution. The two contacting metals, in the presence of an electrolyte, constitute a galvanic cell wherein one becomes cathodic and is protected (the noble metal) and the other becomes anodic and suffers an increased rate of corrosion. If the potential difference is low, the tendency toward corrosion is small. If the E.M.F. is large, the tendency towards corrosion increases correspondingly.

2.0212 During the corrosion process an electric current is generated by the difference in the electrode potential of the two metals in contact. The magnitude of the current determines the acceleration of the corrosion of the more vulnerable material over and above its normal rate of deterioration. Some persons erroneously define the quantity of galvanic corrosion as the total corrosion and thus include the normal decomposition of the metal resulting from its exposure to the environment.

2.0213 In Figure 1, the galvanized steel anchor rod and the galvanized steel 3-bolt clamp act as anodes and the copper-steel guy strand acts as the cathode in an example of a "galvanic couple" caused by connecting two dissimilar metals together. The corrosion of the anchor rod and the 3-bolt clamp will be accelerated over the normal rate of corrosion associated with the atmosphere by virtue of this galvanic effect unless the hardware is provided with some coating to prevent air and moisture from penetrating to the dissimilar metal connection.

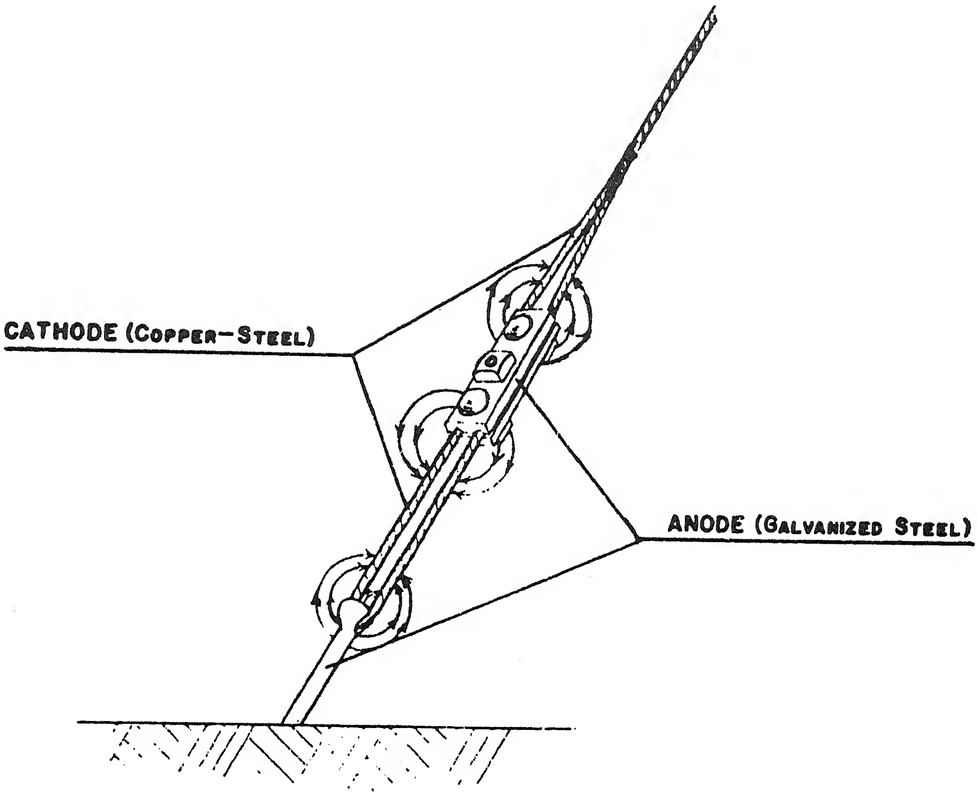


FIGURE I. GALVANIC CORROSION

2.0214 With a knowledge of the galvanic corrosion behavior of metals and alloys, one can arrange them in a series which will indicate their general tendency to form galvanic cells. Thereby, we can predict the probable direction of the galvanic effects. Such a galvanic series is shown in Table I. Such a table is only qualitative and is intended only to indicate trends. It is based on the actual corrosion testing experience within laboratories or under plant operating conditions. It is not to be confused with the Electromotive Force Series which is based upon data collected under carefully controlled conditions wherein the data are quantatively reproducible. In the E.M.F. series the metals are arranged according to the potentials developed by them when immersed in solution of their own ions of prescribed

composition as to strength and chemical nature. This E.M.F. series is of theoretical value, but it cannot be relied upon to predict the potential differences between metals in plant operating conditions.

2.0215 It will be noticed that some of the metals in Table I are grouped together. These group members have little tendency to produce galvanic corrosion on each other and are relatively safe to use in contact with each other. However, the coupling of two metals widely separated in the galvanic series will result in galvanic corrosion of the metal higher in the list, i.e., the one most anodic.

The farther apart the two metals stand, the greater will be this galvanic tendency. The relative position of a metal within a group sometimes change with external conditions, but it is only rarely that changes occur from group to group. It will be seen that the 18:8 and the 18:8:3 stainless alloys are in two places in Table I. They frequently change positions as indicated, depending upon the corrosive media. In environments where these alloys ordinarily demonstrate good resistance to corrosion they will be in their passive (more noble) condition and behave accordingly in galvanic couples.

2.0216 The areas of the two metals forming a galvanic cell have much to do with the rate of corrosion. If a small piece of aluminum is coupled with a large piece of copper, the galvanic corrosion rate of the aluminum will be many times faster than if both metals had the same area. If it appears necessary or prudent to use dissimilar metals in contact with one another, the area of the more active (anodic) metal should be large with respect to the area of the more noble (cathodic) metal.

TABLE I

Galvanic Series of Metals

Anodic End

Magnesium
Magnesium Alloys

Zinc

Aluminum

Cadmium

Steel or Iron
Cast Iron

18:8 Stainless (active)
18:8:3 Stainless (active)

Lead-Tin Solders
Lead
Tin

Nickel (active)
Inconel (active)
Hastelloy (active)

Brass
Copper
Bronze
Copper:Nickel Alloys
Monel

Silver Solder

Nickel (passive)
Inconel (passive)

18:8 Stainless (passive)
18:8:3 Stainless (passive)
Hastelloy C (passive)

Silver

Graphite
Gold
Platinum

Cathodic End

2.022 Concentration Cell Corrosion

2.0221 Galvanic corrosion, discussed previously in paragraph 2.021, results from action of a liquid on two dissimilar metals connected to each other. Another source of corrosion arises from the differences in concentrations within a liquid acting on a single metal. Usually this latter form of corrosion originates in or around hidden or secluded areas. Early detection and prevention depend largely upon familarity with its mechanism.

2.0222 It has been seen that the tendency of a metal to go into solution is influenced by the concentrations of ions of that metal in solution in immediate contact with the metal surface. In general, the lower the metal ion concentration, the greater is the tendency of the metal to dissolve, i.e., the lower the metal ion concentration, the higher is its solution potential. When a single metal surface is exposed to a corrosive environment which is not uniform in its metal:salt concentration ratio from point to point, corrosion results in areas of weaker concentration. Various types of concentration cells can exist in addition to the one mentioned above. Differences in oxygen concentration at metal surfaces within a solution also develop the same kind of potentials at their point of contact with metallic surfaces. In both cases, the zone of greatest attack will be in the area of the more dilute concentration. This principle explains the rapid metal destruction associated with lap joints, crevices, or deposits that interfere with the free flow of electrolyte over the entire surface of the metal.

2.0223 In the one type of concentration cell, differences in oxygen concentration will accelerate the rate of corrosive attack within a crevice where the oxygen concentration is lowest. These cells then are typically associated with crevices or deposits that hinder diffusion of oxygen into the solution under the deposit. In such cases the lower concentration of oxygen makes the area in contact therewith anodic causing corrosion under the deposit or within the crevice of a lap joint and the end result is serious.

With some alloys the effect of oxygen concentration is augmented greatly by the electrolytic cell set up between a relatively small area of activated alloy within the crevice and a large area of passive alloy around the crevice. These active-passive cells then are similar to, but generally more powerful than, normal oxygen cells. This type of corrosion is likely to be found in stainless steels, although any metal which has been treated to form a protective coating may also be affected. Figure 2 shows the concentration cell corrosion that causes the failure of corrosion resistant steel (stainless steel) cable suspension strand in industrial and marine atmospheres. Dirt and soot from an industrial area or salt deposits in a marine atmosphere settle upon the surface, enter into the interstices of the strand and have a tendency to hold moisture. A differential aeration cell is thus set up and the steel that is under the deposit becomes active and is anodic to the passive steel on the outer surface of the strand. Pitting of the stainless steel on the inside of the strand under the deposits will result, leading to what is referred to as stress corrosion cracking.

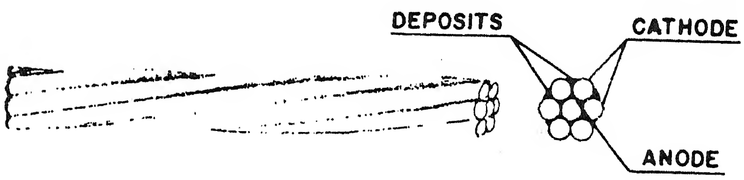


FIGURE 2. CONCENTRATION CELL CORROSION

Galvanized steel strand on the other hand will behave quite differently under the same atmospheric conditions. The zinc on the galvanized steel strand will protect the steel until it is completely consumed. The outside surfaces of the strand can be quite badly rusted at the same time that the inner surfaces of the strand are relatively unaffected.

2.0224 Certain metals form tight protective oxide films that normally resist corrosion. Such a film repairs itself in case of a breakthrough if sufficient oxygen is present to reoxidize the base

metal and maintain its passive nature. In the absence of sufficient oxygen to keep these oxide films in repair the metal in that area favors an active state for these hidden surfaces, and as in the case of the oxygen cell, pitting occurs within the joint or under the deposit. Similarly, concentration cell corrosion may occur on metal surfaces which are covered with nonmetallics. If voids or accidental openings in a protective coating occur which permit moisture to enter under the coating, this type of corrosion can result. Severe pitting may result through this local action and the net result may be more severe than if the entire metal area were exposed.

2.023 Stray Current Corrosion

2.0231 Since corrosion is electrochemical in nature, ordinarily used metals will corrode whenever current leaves the metal to pass into the electrolyte, regardless of the source of the current. Damage due to direct currents of external origin leaving a metal is known as stray current corrosion. This type of corrosion was noted years ago when direct current was used widely in industry for variable speed drives in transit systems and load-carrying devices. In recent years lead sheathed telephone cables buried by telephone companies in the rural areas have been adversely affected by cathodic protection applied to cross-country pipe lines. Not long after the early cross-country pipe lines were put in that the gas companies discovered that their pipes were being severely corroded because of stray earth currents. Thereafter, cathodic protection and other means were employed to minimize the corrosion of the pipelines. In cathodic protection, a negative potential is impressed on the pipe line which causes stray earth currents to flow in the direction of the pipe line, thus protecting it against stray current corrosion. The conductivity of most metals is in the order of several thousand times the conductivity of average soils, and therefore any buried metallic pipes or cables in the vicinity of the pipe lines act as low resistance paths and tend to collect these stray earth currents which may be flowing through the surrounding earth electrolyte. At the point where the stray currents enter such

auxiliary conductors the earth becomes anodic and the pipe or cable cathodic. When the currents leave the metallic cable near the cathodically protected pipe line (see Figure 3), that metallic area becomes anodic and localized corrosion can be quite severe.

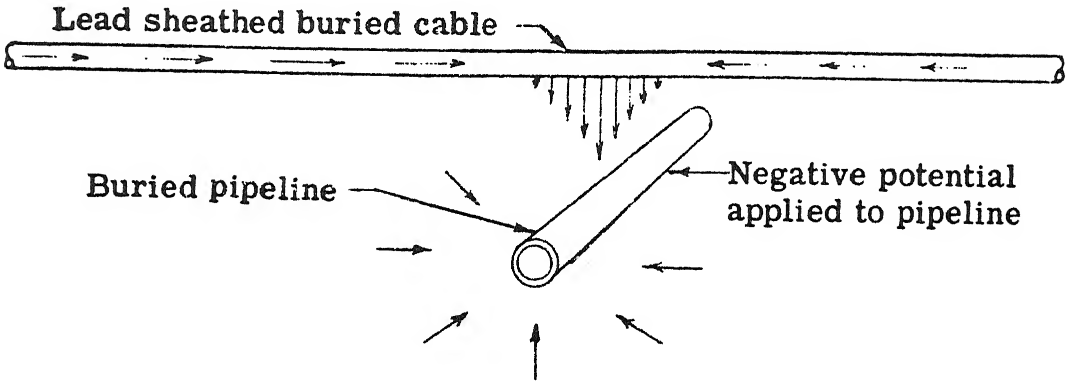


FIGURE 3. STRAY CURRENT CORROSION

2.0232 Stray current corrosion differs from galvanic corrosion in several respects. The damage caused where the direct current from an external source leaves a grounded metal is independent of the oxygen concentration of the surrounding environment. Stray currents usually have sufficient voltage to force hydrogen discharge so corrosion is not limited to the oxygen which is available for depolarization. Likewise, stray current corrosion is not controlled or minimized by deposits of corrosion products or protective coatings unless the latter are perfect insulators.

3. CORROSION BEHAVIOR OF MATERIALS USED IN TELEPHONE OUTSIDE PLANT CONSTRUCTION

3.01 Atmospheric Environments - In recent years REA has become increasingly aware of the need for special attention in the choice of materials and construction practices to be used in those areas of the United States where plant maintenance and replacement costs are excessively high because of the corrosive nature of the atmospheres which are predominant, namely, industrial, marine and rural.

3.011 Industrial atmospheres are among the most corrosive. The atmosphere around industrial plants may contain sulphur

oxides and carbon dioxides in relatively high concentrations. Sulphur oxide and carbon dioxide both form acid films on exposed metals and some of the pollutants present in the atmosphere attract moisture. Consequently, atmospheres high in these contaminants usually are very corrosive.

3.012 Marine atmospheres, because they are associated with the coastline of the United States and more easily located geographically than industrial areas, have been generally designated on maps contained in REA TE & CM-218. The depth of these coastal areas vary from approximately two miles to as much as twenty miles from the ocean. In some areas, such as along the Gulf Coast of Louisiana and Texas, corrosive atmospheres exist as deep as one hundred miles from the coast due to a combination of salt atmosphere and industrial fumes.

Sea air contains chlorides and may contain traces of sulphur, carbon dioxide and other components that, over a period of time, can become quite concentrated on metal surfaces. Furthermore, in areas immediately adjacent to the shore, the salt spray from the ocean thrown up by strong breezes contribute to the buildup of sea salt deposits on metals and keep them wet a good portion of the time.

3.013 The third type of predominant atmosphere that prevails in the United States is that referred to as a rural atmosphere. It is in these rural areas, that represent approximately 80% of the total area of the United States, where exposed metals are expected to obtain their longest possible life. The typical inland country atmosphere is relatively free from contaminants, consequently, it is not generally very corrosive. For this reason, exposed metal in rural atmospheres may last a substantial number of years without serious deterioration.

3.014 In the paragraphs that follow the materials used in the REA program and their performance in the different types of corrosive atmospheres will be discussed.

Again it should be stressed that while all atmospheres contain contaminants in varying degrees of concentration, the behavior of the materials described in the following paragraphs is related to the most severe concentration of corrosive elements.

3.0141 Galvanized steel is widely used in the REA program for both hardware items and for strand and conductors. In industrial atmospheres the corrosion products on galvanized steel are basic zinc sulfate and basic zinc carbonate with the sulfate predominating. The sulfate is more soluble than the carbonate and is removed both by being dissolved and being blown off by wind and rain, whereas the carbonate is removed chiefly by the erosive action of wind driven dirt and dust. This loss of corrosion products results in a high rate of deterioration of the zinc in industrial atmospheres. The chlorides present in the marine atmospheres will strongly attack the zinc coating on galvanized steel items to form a zinc chloride. This zinc chloride compound will attract and hold moisture and will react with other elements in the air to form zinc oxychloride and zinc carbonate. This coating is quite porous and powdery in nature and can quite easily be washed off. Because of the moisture laden winds along the coast these corrosion products can build up faster than the rain can wash them off. Since the material remains wet most of the time the corrosion will progress until the zinc is completely changed to these compounds.

As in the industrial area, the chemical composition of the base steel will affect the oxide coating formed on the steel after the zinc has been dissipated. Carbon steel will develop an oxide coating which will be quite porous and flaky. It is not soluble but may be quite readily dislodged. Thus the carbon steel will continue to corrode until it disappears. The oxide coating on the low alloy steel will be less porous and more adherent. The rate of diffusion of corrosive elements to the base metal will be lower than with the carbon steel and thus the low alloy steel will be more corrosion resistant.

3.0142 Copper and its alloys as well as copper-covered steel are used to a great extent in the REA telephone program for conductors and a variety of

fittings. Copper is most sensitive to the sulphur oxides present in the industrial atmospheres. New copper exposed to this atmosphere will form a copper oxide coating which is not too porous but is quite brittle. The sulphur dioxide and moisture in the air will combine with the copper oxide to convert part of it to basic copper sulfate. It is this copper sulfate coating that gives the familiar green "patina" appearance on copper. The recognized low rate of copper corrosion in the atmosphere is due to this protective patina. As long as this coating is not disturbed the corrosion reaction will continue, but at a very slow rate. However, the cuprous oxide underlayer is very brittle and can easily be dislodged. If this happens, fresh copper is exposed anew to the accelerated corrosion process. Where copper-covered steel is used as a conductor under tension, this somewhat protective coating can be dislodged by vibration or abrasion. Copper and copper-covered steel will probably corrode at a faster rate in a marine atmosphere than in an industrial area because of the presence of chlorides and also traces of sulphur. The surfaces of the metals are apt to remain wet a large share of the time because of the salt spray. The copper would react with oxygen to produce a layer of basic copper oxide which is converted to basic copper sulfate and basic copper chloride in the salt air. The same copper oxide would be present as in the industrial area but its combination with the chloride would cause the corrosion reaction to be stronger. The coating would probably be more porous and hold more moisture and would allow more air to diffuse through to the base metal to stimulate the corrosion of the copper. In the case of copper-steel conductors, there is a relatively thin layer of copper over the base steel and the tendency for the steel to be exposed is very real. Once the steel is exposed to the atmosphere it becomes anodic to the copper. Since the exposed area of the steel (anode) is small compared to the area of the copper (cathode) on the surface of the wire, the galvanic cell set up is very strong and the corrosion of the steel will be very rapid.

3.0143 Some use has been made of corrosion resistant steel (certain grades of stainless steel) for cable suspensio

strand and guy strands in industrial and marine areas in the hope of giving additional life over that offered from Grade C galvanized steel strand. Corrosion resistant steel forms an oxide coating which is quite protective in nature when it is exposed to the atmosphere. Corrosive elements in the industrial and marine atmospheres find it very difficult to penetrate this protective coating and attack the base steel. However, this material is subject to corrosion of a different nature. When dirt and soot from industrial atmospheres and salt deposits from marine atmospheres settle upon the surface and into the interstices of the strand, a concentration cell is set up as described in paragraph 2.0223. The corrosion resulting from this concentration cell and the subsequent stress corrosion cracking of the strand is quite serious. Cable suspension strand made of stainless steel can look perfectly good today and fail tomorrow because of the pitting that usually occurs inside the strand where it is not apparent from visual inspection. For this reason there is a tendency for outside plant engineers to favor the use of Class C galvanized steel suspension strand over that of the corrosion resistant steel. Although the Class C galvanized steel strand has a shortened life span in a corrosive atmosphere, its replacement can be planned whereas the failure of the corrosion resistant steel strand can not be predicted with as much certainty. The serious effects of premature or unexpected failure of a suspension strand carrying cables having a large number of pairs can not usually be tolerated.

3.0144 A new type of wire facility has recently been offered to the telephone industry which appears to offer substantial benefits to a telephone company in industrial type atmospheres. This conductor is made of aluminum-covered steel and theoretically would be better from a corrosion standpoint in an area of high sulphur than the other three materials previously mentioned. Water and oxygen from the air will combine with the aluminum to form a coating of aluminum oxide which will be highly protective to the aluminum covering and thus will protect the base steel. There are potential advantages of aluminum-covered steel or aluminum alloy hardware in these highly corrosive areas. So far, the exposure

tests being conducted by REA and the ASTM have been encouraging and work is being carried out for further evaluation of these materials.

3.0145 The three basic types of atmospheres, namely industrial, marine and rural, found within the boundaries of the United States have been described in the previous paragraphs. It is important to realize that within these general areas there may exist commercial operations that would change the characteristics of the atmosphere in that environment and might indicate the possibility of accelerated corrosion. Such operations might include drilling or mining installations, chemical plants, fertilizer plants, burning slag dumps, sour gas fields, etc., where air pollution is high. Also in hot, humid areas vegetation such as Spanish Moss which collects and grows along the lines may be a cause of serious corrosion. All of these factors should be kept in mind when considering the possibility of atmospheric corrosion of telephone outside plant facilities.

3.02 Underground Environments - In the REA telephone program, the underground plant consists mainly of anchors, anchor rods, grounding rods, some systems of lead sheathed buried cable, and in recent years the buried plant terminal housings and buried cables and wire. From experience, it has been determined that the corrosion of anchor rods is the most important aspect of underground plant to give the REA borrower reasons for concern. The corrosion of galvanized steel anchor rods may be caused by dissimilar metal effects (galvanic couples), soil conditions (differential salt concentration or differential aeration), or by stray currents. Lead sheathed buried cable is also subject to corrosion from differential aeration conditions and from stray currents. Where the lead sheathed cable is bonded to the grounding system for lightning protection purposes, it is also subject to galvanic corrosion.

3.021 It has been the general practice to use copper or copper-covered steel ground rods for grounding of metallic facilities or structures. It is also the practice on joint use construction, where the power system is of the multi-grounded neutral type, to bond the guy strand to the neutral either directly or through the cable suspension strand. The zinc and iron in a galvanized steel anchor rod, when buried in conducting earth, tend to assume a d-c voltage that is more negative than that of buried copper. When the buried steel

and copper are connected together by way of the system neutral, as shown in Figure 4, currents will begin to flow through the earth from the steel to the copper ground rod and the copper pole-butt grounds. Corrosion associated with such current flow is referred to as galvanic corrosion.

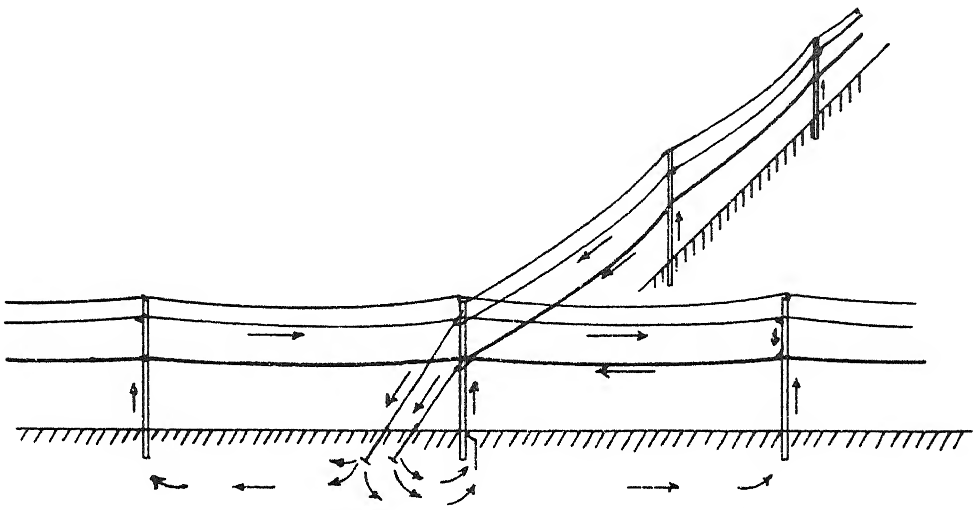


FIGURE 4. ANCHOR ROD CORROSION—GALVANIC COUPLE

Polarizing effects occur at the steel and copper surfaces in most soils and interefere with the flow of current so that it soon decreases to the point where no important damage occurs. In the more corrosive soils, however, the current may continue to flow so that the steel is corroded at an excessive rate. Excessive underground corrosion is generally noticed on anchor rods first, and in many cases anchor rod corrosion is believed to be the entire problem. It is important to realize that other buried structures may be affected as well. Any buried structure connected to the system neutral may be corroded as a result of galvanic action.

Ungalvanized anchors are considered an important contributor to corrosion of steel anchor rods and may be the major contributor where the corrosion is not associated with currents

in guys due to copper grounds. The mill scale on hot rolled steel and oxide films on other steel or iron shapes is cathodic with respect to galvanized and bright steel surfaces, and thus contributes to galvanic corrosion of the bright surfaces in much the same way as copper. Galvanizing of anchors requires prior removal of all oxide films, and the galvanizing offers additional corrosion protection to the anchor rod as well as to the anchor.

3.022 Differential Aeration Cells - Corrosion of an anchor rod can occur, regardless of the material used, even though it is electrically isolated from the MGN if the soil conditions are not favorable. A differential aeration cell (see Figure 5) may be set up on the surface of the anchor rod where the lower portion of the rod in contact with soil that is lacking in oxygen content becomes anodic to the upper portion of the rod which is in contact with soil having higher oxygen content. Most corrosion failures of anchor rods occur within six inches of the anchor, and other structures also are likely to have the greatest damage deep in the ground where moisture is present and oxygen may be excluded.

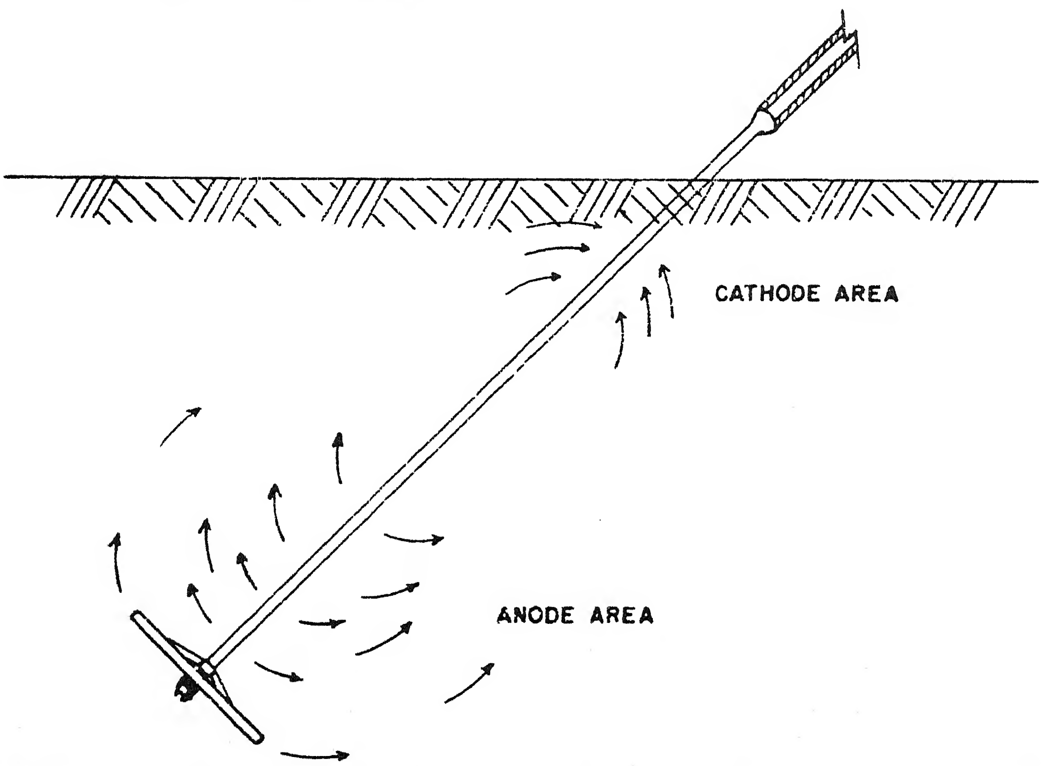


FIGURE 5. ANCHOR ROD CORROSION—DIFFERENTIAL AERATION CELL

3.023 Stray Currents - REA borrowers have been faced on a number of occasions with corrosion problems resulting from cathodic protection being applied by pipe line companies to their cross country pipe lines. Two or three cases involved lead sheathed paper cable that was placed in the ground several years before there were many of the cross country pipe systems. These telephone companies were not aware of the pipe lines being in the vicinity of their buried cables until they went looking for the cause of the lead sheath corrosion (see Figure 3). Stray currents from these cathodic protection systems can cause relatively rapid corrosion of anchor rods, ground rods, metal sheathed cables, and other metallic structures placed underground. The first signs of stray current damage is likely to be failure of one or more anchor rods in low or wet locations, and in a majority of cases this can be noted from slack guys before further damage occurs.

4. CORROSION PREVENTIVE MEASURES

4.01 Atmospheric Environments - The engineer should, during the early stages in the design of the telephone system, determine the type or types of atmospheric environments that exist in the area of the proposed construction. Corrosive atmospheric conditions may exist generally over an entire service area of a telephone system or may be confined to relatively small areas within the total service area. In a heavily industrial area that spreads over several square miles, the entire project area may be contaminated and require special corrosion consideration. On the other hand, in an area that is generally considered to be rural, a commercial operation may be located that would adversely affect the life of just a few miles of telephone plant. One of the most valuable sources of information relative to the experience on the behavior, in that particular area, of the various materials available for use is the telephone plant that is being replaced. Obviously, if the material in the plant being replaced has been in service for 20 or 25 years there is no reason for serious concern. When it is not possible to determine the life of the existing plant because of lack of records or personnel who remember when a certain section of line was built, the local electric utility may be able to furnish the necessary information. Many of the materials and the problems in the use of these materials are common to both the telephone and the electric utilities. A survey of the commercial and industrial activities in the service area may point out those areas where special corrosion preventive measures should be taken.

4.011 Once the type of atmosphere involved in the proposed area of construction has been identified, a determination of materials best suited for use in the particular environment should be made. The information contained in Table II is intended as a general guide for the proper choice of materials to be used in the most severe of the various types of atmospheres. Some of the information in this table is theoretical because only limited experience is available upon which to base recommendations. Obviously, if the information in Table II indicates that more than one type of material is suitable for application, the final choice of material should be based upon economics. The areas immediately adjacent to the east coast and to the northwest coast of the United States would be classified as marine, whereas the areas within 20 miles of the Gulf Coast of Louisiana and Texas and the coast of California south of San Francisco would be classified as marine industrial. In the Gulf Coast areas of Louisiana and Texas, the belt from 20 miles to 100 miles from the coast would be classified as industrial because of the numerous oil wells, chemical processing, and oil and gas refinery operations.

4.0111 Galvanized steel has been widely used for many years in the telephone industry for hardware items. Generally speaking, hardware items such as 3 bolt clamps, cable suspension clamps, machine bolts, thimbleye bolts, etc., are available only in galvanized steel. However, in the past couple of years investigations have been made as to the possible use of aluminum-covered steel or aluminum alloy hardware items. In severe industrial areas, where galvanized steel would have a shortened life, the use of aluminum-covered steel or aluminum alloy hardware is recommended where available. Until this material becomes generally available galvanized steel hardware made from low alloy steel should be used in preference to carbon steel.

4.0112 One of the most important considerations in the proper choice of materials to be used in a given environment is to choose metals that will give good performance when fastened together. Metals that are widely separated in the galvanic series (Table I) should be avoided where they are to be

placed in contact with one another. If it is not possible to avoid the use of dissimilar metals, it is important to remember that the least damage occurs where the ratio of exposed area of noble (protected) to the exposed area of less noble (corroding) metal surfaces is kept as small as possible. All solid or stranded wire used for bonding or grounding purposes should be of tinned copper to minimize the effects of connecting dissimilar metals. In those cases where the bonding or grounding wire is to be used underground, it should be of insulated tinned copper. Whenever it is necessary, because of the proper materials not being available, to connect dissimilar metals together in the construction of outside plant facilities, the connections should be adequately covered with an application of Kearney "Airseal," Joslyn "Seal-Ox" or equivalent. When properly applied, these materials will prevent moisture and air from coming in contact with the dissimilar metal connection and thus prevent corrosion of the joint.

4.0113 Galvanized steel has been used for many years in the telephone industry for line conductors, cable messenger strand, and for guy strand. For the past several years copper-covered steel has been enjoying an ever increasing use in REA borrowers' systems as a telephone line conductor. As discussed previously, these two types of material are not fully acceptable for application in the most severe industrial and marine atmospheres. Experience to date would indicate that aluminum-covered steel line wire, messenger strand, and guy strand should be used in areas high in sulphur content, such as severe industrial atmospheres and near sulphur mining activities.

4.0114 Table II shows that polyethylene insulated facilities are expected to experience good performance characteristics in all types of atmospheres. Serious consideration should be given to the use of insulated wire and cable products in areas that are highly corrosive, since in most cases substantial corrosion protection is achieved at no additional expense. The use of the Figure 8 cables and distribution wires should give very satisfactory results where proper attention is given to the restoration of the insulation over the support member

when it is damaged or removed for installation purposes. In those areas where transmission requirements can not be met with the exclusive use of the Figure 8 distribution wires, insulated line wire can be used on the extremities of the telephone circuits to the extent that transmission requirements are met.

4.02 Underground Environments - The major concern in the underground corrosion of telephone systems is the difficulty associated with anticipating where excessive corrosion will occur because of the many factors that singly or in combination affect the course of the electrochemical reaction. The major problem in corrosion prevention is to decide on the corrective measures that will give satisfactory results at least cost with a minimum of disadvantages to the electrical behavior of the facilities and a minimum of adverse effects on subscribers and others. The important need is to adequately recognize the things that are happening or can happen and the alternatives available, so that future corrosion problems can be minimized instead of being "built in" each time that a system is designed, constructed or modified.

The recommendations set forth in the following paragraphs are intended to minimize underground corrosion of buried metal that is connected to or a part of the electrical grounding system and to reduce the difficulty and the cost of applying cathodic protection where needed for further reducing the amount of underground corrosion.

4.021 Galvanic corrosion, caused by connecting dissimilar metals underground, has been the most prevalent and most serious type of corrosion experienced by the telephone and electric utility industries. In order to eliminate or to minimize galvanic corrosion of galvanized anchor rods, subscriber's plumbing and well casings, and other metals connected to the grounding system, it is recommended that grounding of electrical protection apparatus on telephone systems of REA borrowers be accomplished in accordance with the guidelines contained in the following paragraphs:

4.0211 It should be the general practice to install galvanized steel ground rods wherever the station protector assembly unit requires a driven ground. The interconnection or common grounding of the telephone protector, electric service

ground, and metallic water pipe constitutes the most important principle of safeguarding the customer and his equipment against shock and fire hazards. This principle should not be sacrificed under any circumstances.

4.0212 Where a driven ground rod is required for electrical protection purposes in buried plant construction, a galvanized steel ground rod should be used.

4.0213 On pole line construction, where a driven ground rod is required for electrical protection purposes and is to be interconnected with the guy and anchor assemblies, a galvanized steel ground rod should be used. In the event the ground rods are not interconnected with the guy and anchor assemblies a copper-steel ground rod may be used.

4.0214 Where joint use construction is contemplated with a multigrounded neutral power system, inquiries should be made of the electric company as to its history of underground corrosion. In the event that the electric company has experienced corrosion in its underground plant, a corrective program may have been established. If so, the telephone system should follow a similar program. If there has been no experience of underground corrosion on the electric system, standard construction practices can probably be followed with satisfactory results.

4.0215 The use of galvanized anchors, in addition to the galvanized anchor rods, will further reduce the rate of corrosion. A substantial amount of protection against corrosion can be achieved in this way at very little increase in cost. This is especially important in areas of low earth resistivity.

4.022 Stray current corrosion, as described in paragraph 2.0231, can be reduced in underground telephone plant by either electrically insulating the telephone facilities from the stray currents or installing a mitigation bond between the telephone facilities and the foreign structure being cathodically protected. Usually the anchor rods and anchors can most easily and economically be protected by insulating them from the d-c source, unless a mitigation bond can easily be provided between the d-c source and a MGN. If stray current

corrosion is being experienced on buried metallic sheathed cables, the best method probably will be to install a mitigation bond (see Figure 6).

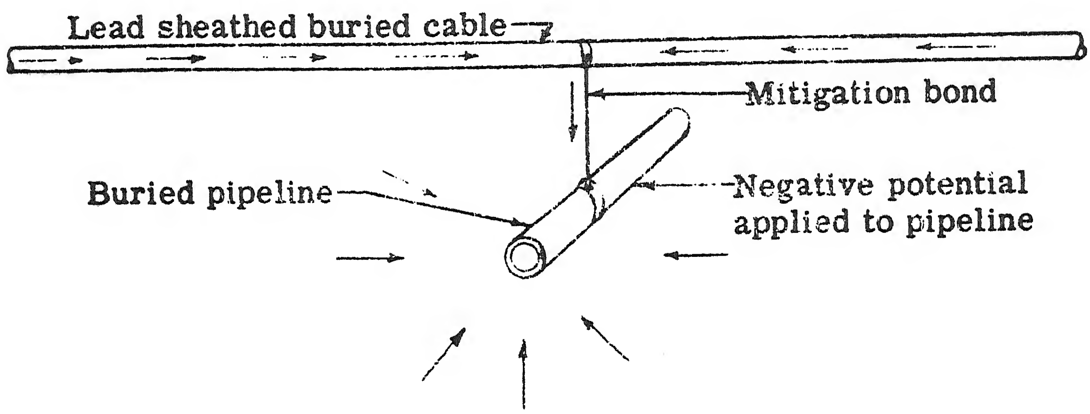


FIGURE 6. COORDINATED STRAY CURRENT PORTECTION

When new construction is being contemplated in the vicinity of a buried pipe system, municipal water system, or gas utility system, a determination should be made as to the corrosion protective measures being employed to protect such structures and to what extent this protection might adversely affect the performance of the telephone underground facilities. Every attempt should be made to outline a program with these companies that will assure the telephone borrower of the maximum practical protection against corrosion from the effects of the system employed to protect the foreign structures. Figure 6 shows an example of a coordinated effort to arrest the corrosive effects of the stray currents shown in Figure 3. A mitigation bond was placed between the buried lead sheathed cable and the cathodically protected pipe line to provide a low resistance path back to the rectifier station for the stray currents.

Characteristic Corrosive Atmospheres	Polyethylene Insulated Cable & Wire Facilities	Copper & Copper Alloys	Copper Covered Steel	Class C Galvanized Steel (carbon)	Class C Galvanized Steel (low alloy)	Stainless Steel Strand	Stainless Steel Sheet	Aluminum Covered Steel ***	Aluminum Alloys ***
Industrial									
Steel Mills	G	G**	P	P-F	F-G	F	G	G	G
Galvanizing Plants	G	G**	P	P-F	F-G	F	G	G	G
Chemical Processing	G	F	P	P-F	F-G	G*	G	G*	G*
Coal Mines - Burning Slag Dumps	G	P	P	P-F	F-G	F	G	G	G
Fertilizer Plants	G	F	F	P-F	F-G	F	G	F	F
Oil Refineries	G	F	P	P-F	F-G	F	G	G	G
Oil Wells	G	G	P	P-F	F-G	G	G	G	G
Paper Mills	G	G	P	P-F	F-G	F	G	G	G
Sour Gas Fields	G	F-G	P	P-F	F-G	F	G	G	G
Sulphur Mines	G	F-G	P	P-F	F-G	F	G	G	G
Industrial Marine	G	F-G	P	P-F	F-G	P	G	F-G	F-G
Marine	G	F-G	P	P-F	F-G	P	G	F	F

Telephone Outside Plant Materials

G - Good
F - Fair
P - Poor

* Except when chlorides are present, in which case F
** Unless protective oxide coating is disturbed
*** Theoretical performance

TABLE II - PERFORMANCE OF OUTSIDE PLANT MATERIALS IN VARIOUS ATMOSPHERES